ASMEORC 2013
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TECHNICAL, ECONOMICAL, AND ENVIRONMENTAL COMPARISON BASED ON EXERGY ABOUT UTILIZING HEAT OF COGENERATION FOR COMFORT COOLING WITH ORC DRIVEN CHILLERS OR HEAT PUMPS VERSUS ABSORPTION/ADSORPTION CYCLES

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Scope

- Exergy justification of cogeneration (CHP)
- Classical tri-generation
- *Primary Energy Savings* (***PES***) according to **EU Directive 2004/8/EC**
- Exergy-upgraded *PES* according to *Rational Exergy Management Model* (***REMM***).
- Exergy-101: Solution Algorithm by *REMM*

- Analysis
  - **Base Scenario :** Conventional Tri-generation with heat-operated cooling
  - **Scenario 1** **:** Trigeneration with ORC and electric-operated chillers
  - **Scenario 2** **:** Tri-generation with ORC and ground-source heat pumps

- Comparison of results
- Discussion
- References

Introduction

- **Efficient** and **rational** use of fossil fuels lead to an increasing interest in cogeneration and tri-generation.

- The rationality mainly depends on how the thermal output of the system is utilized. It is important to generate more electric power first rather than heat to maximize the exergy output like in a bottoming cycle - **electric power has more exergy than heat**.

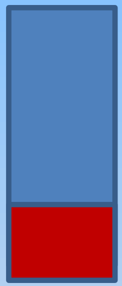
- Tri-generation systems generally use absorption or adsorption cycles to generate cold for cooling.

- This study investigates whether an ORC-based system has advantages, especially when combined with a ground-source heat pump.

Exergy Justification of Cogeneration

If exergy is destroyed prior to application(s).

$$\psi_{Rij} = \frac{\varepsilon_j}{\varepsilon_i}$$



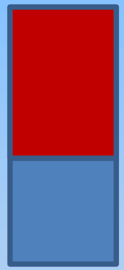
Boiler

$$\varepsilon = \left(1 - \frac{T}{T_{ref}}\right)$$

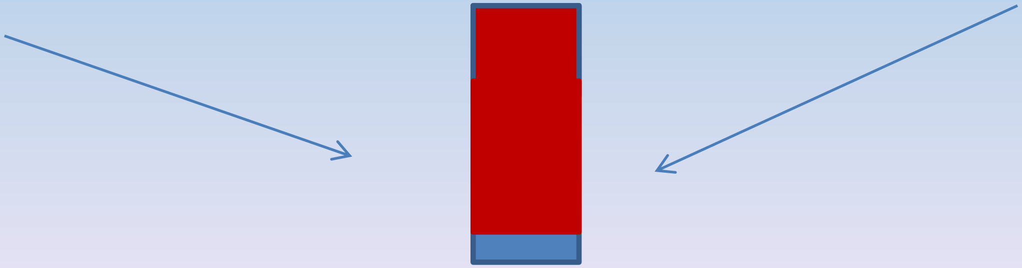
In cooling

If exergy is destroyed after application(s)

$$\psi_{Rij} = 1 - \frac{\varepsilon_d}{\varepsilon_i}$$

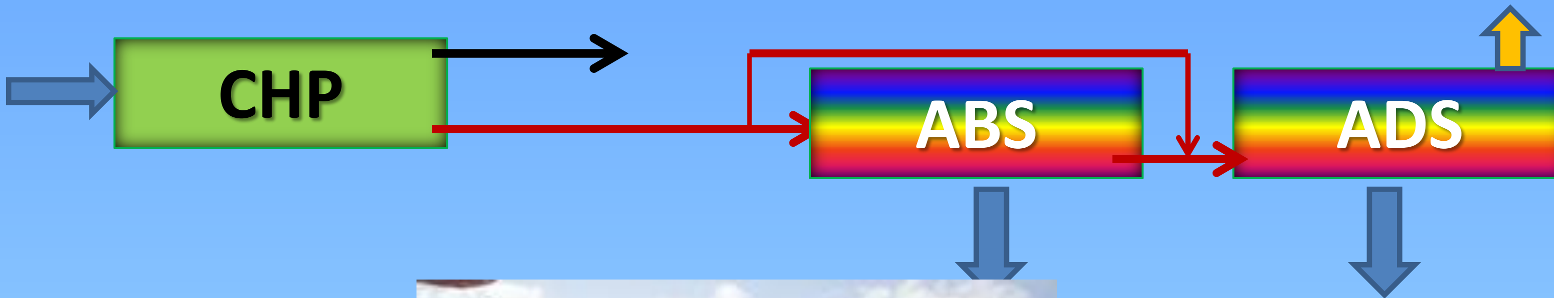


Generator



Co-generation System

Classical Tri-generation



In a classical tri-gener … al output of the CHP
unit is utilized for gen … tion machine and
sometimes in a tande … vith supplementary
heat. This tandemizat … MWe Trigeneration
system for Turgut Öza …
In this system, the ele … is almost entirely
saved for electric power demand points.

The overall exergy efficiency is around 0,35 and the COP_c is 0,40 from the fossil fuel input point.

Primary Energy Savings- EU Directive

$$PES = 1 - \frac{1}{\frac{CHPH\eta}{\mathrm{RefH\eta}} + \frac{\mathrm{CHPE\eta}}{\mathrm{RefE\eta}}}$$

Reference Values		Explanation
RefHη	0,85	Partial efficiency of thermal output in cogeneration
RefEη	0,52	Partial efficiency of electrical power output

Exergy Upgraded Primary Energy Savings - REMM

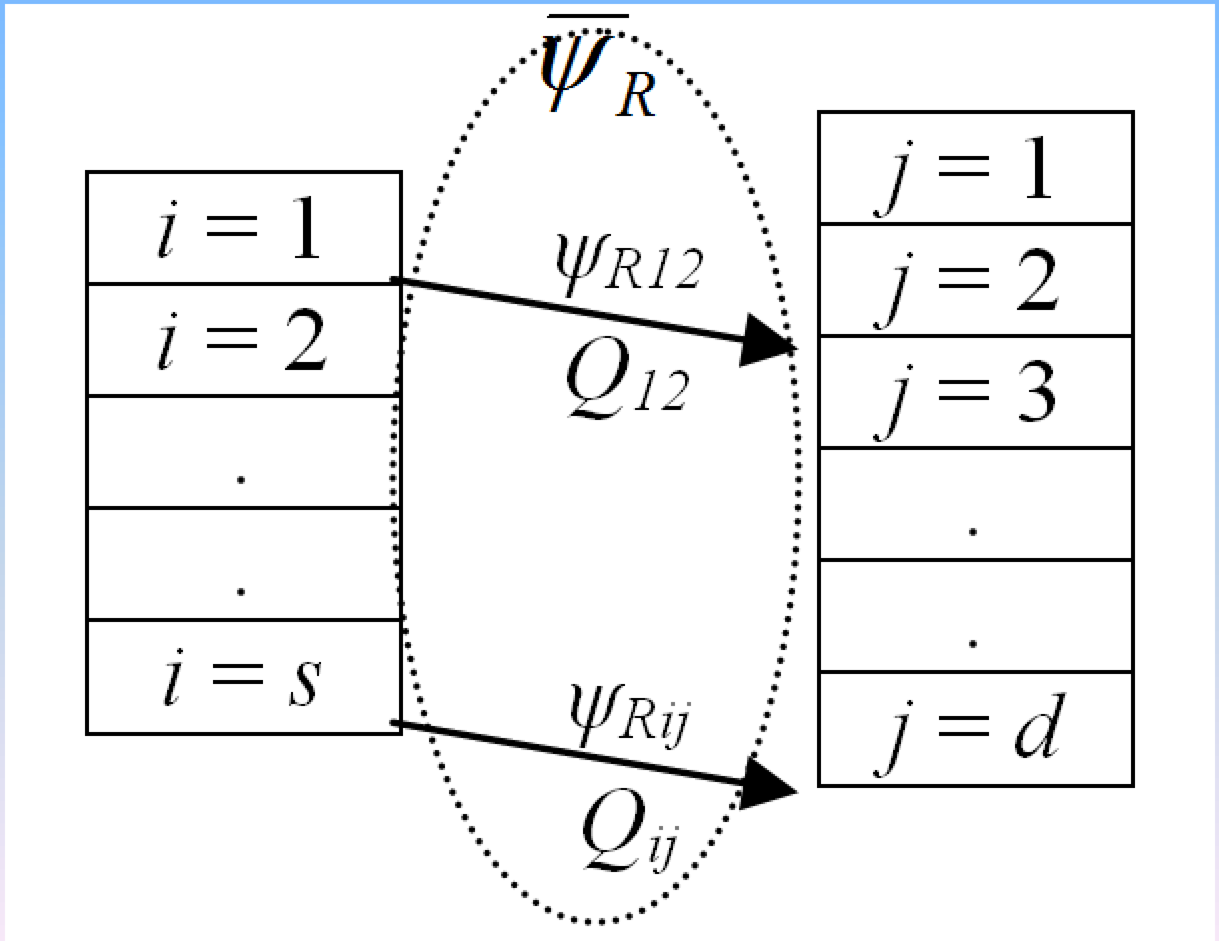
$$PES_{\psi} = 1 - \frac{1}{\frac{1}{\mathrm{RefH\eta}}\left[CHPH\eta - aH_{D}\eta\right] + \frac{\mathrm{CHPS\eta}}{\mathrm{RefS\eta}} + \frac{\mathrm{CHPE\eta}}{\mathrm{RefE\eta}} + \sum \frac{PER}{RefPER} \times \frac{\left(2 - \mathrm{Ref}\,\overline{\psi}_{R}\right)}{\left(2 - \overline{\psi}_{R}\right)}}$$

Reference Values		Explanation
RefHη	0,85	Partial efficiency of thermal output in cogeneration
RefEη	0,52	Partial efficiency of electrical power output
RefSη	0,75	Partial efficiency of steam output
RefPER	1,28	Primary energy ratio in heating (Heat pump)
RefPER	0,96	Primary energy ratio in cooling (Heat pump)
$\mathrm{Ref}\,\overline{\psi}_{R}$	0,204	[Şiir Kilkis, 2011)

$$PER = \eta_{l}\eta_{T}COP$$

Exergy-101 Solution Algorithm with REMM

The primary objective is to maximize $\overline{\psi}_R$



Exergy-101

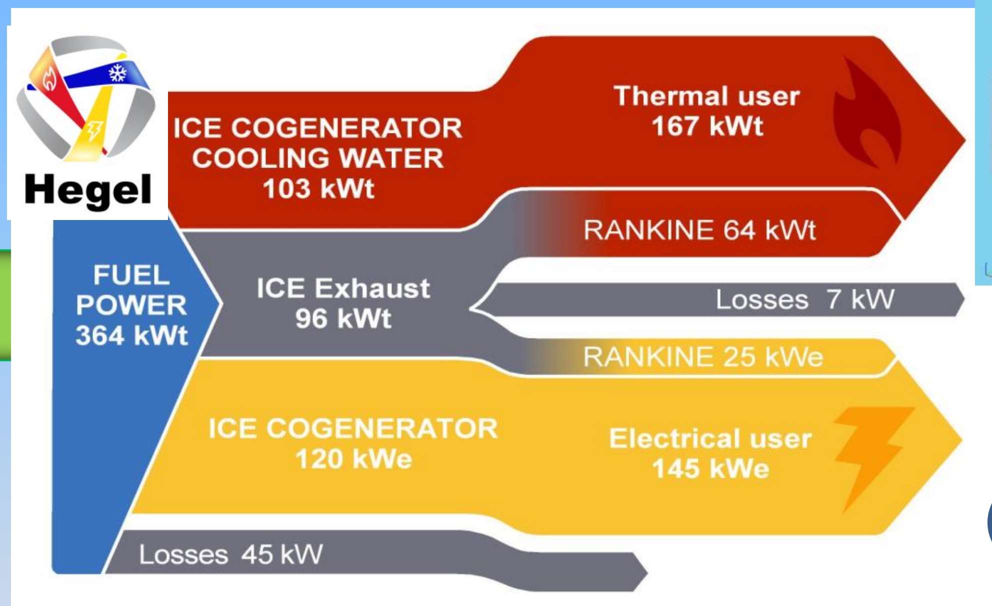
$$M = \begin{vmatrix} \psi_{11}Q_{11} & \psi_{12}Q_{12} & \psi_{13}Q_{13} & \psi_{14}Q_{14} \\ \psi_{21}Q_{21} & \psi_{22}Q_{22} & \psi_{23}Q_{23} & \psi_{24}Q_{24} \\ \psi_{31}Q_{31} & \psi_{32}Q_{32} & \psi_{33}Q_{33} & \psi_{34}Q_{34} \\ \psi_{s1}Q_{s1} & \psi_{s2}Q_{s2} & \psi_{s3}Q_{s3} & \psi_{sd}Q_{sd} \end{vmatrix}$$

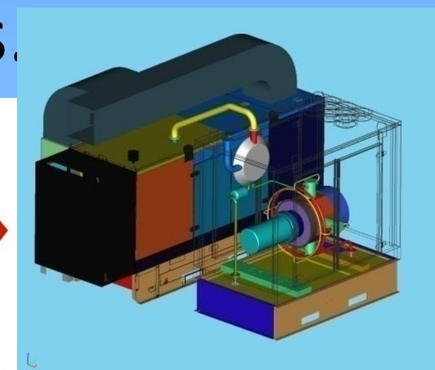
$$\overline{\psi}_R = \frac{\sum_{i=1}^{d}\sum_{j=1}^{s}\psi_{rij} \times Q_{ij}}{\boxed{\sum_{i=1}^{d}\sum_{j=1}^{s}Q_{ij}}}$$

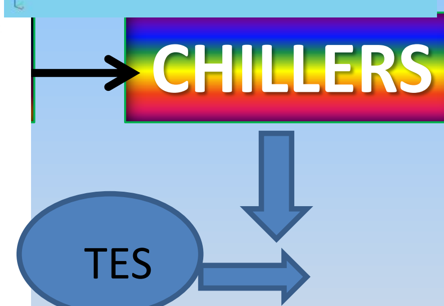
$$\overline{\psi}_R = \frac{tM}{tN}$$

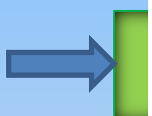
Analysis

- **Scenario 1** - ORC driven chillers.





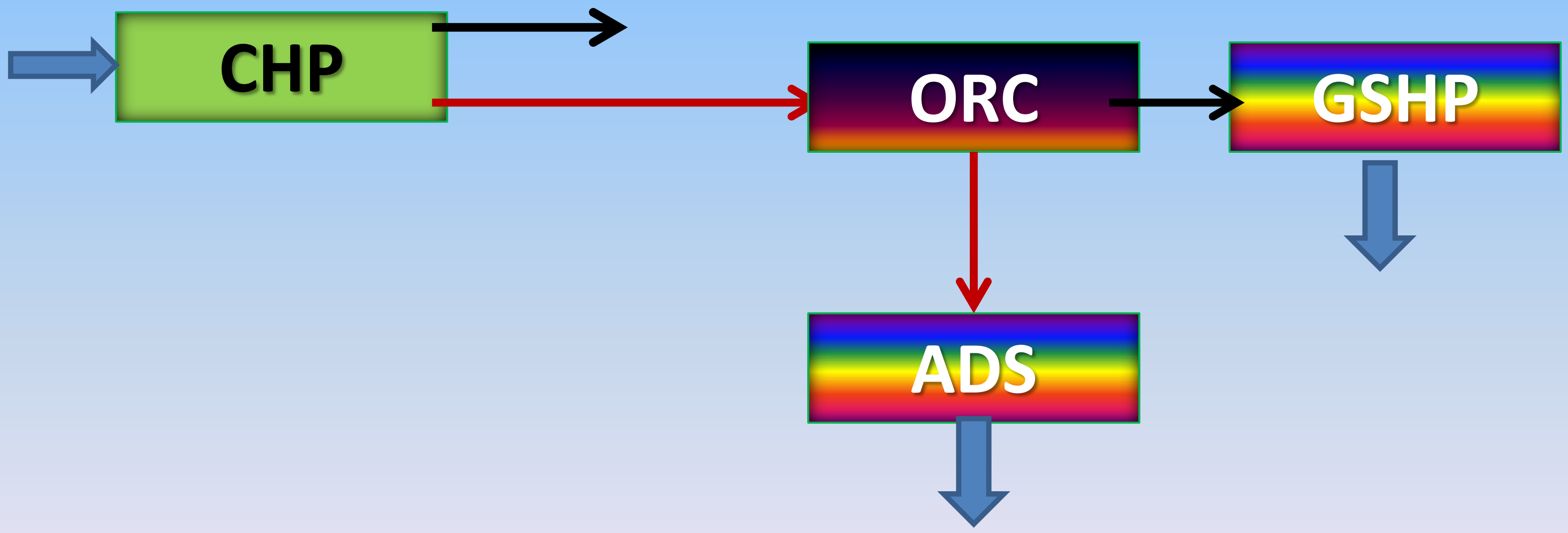




With a design chiller with COP_c of 3,0 and ORC efficiency of 0,1 the overall COP_c from the fuel input point is about 0,15. Here the thermal efficiency of the CHP unit is taken 0,5. However , the exergy efficiency of this scenario increases to about 0,45.

Analysis

- Scenario 2- ORC driven GSHP



In this system, the overall *COP_c* is about 0,5 and the exergy efficiency is 0,55.

COMPOUND CO_2 EMISSIONS

$$\sum CO_2 = \left[\frac{c_l}{\eta_l} + \frac{c_m}{\eta_m \eta_T}\boxed{\left(1 - \overline{\psi}_R\right)}\right]Q + \frac{c_m}{\eta_m \eta_T}E$$

Results And Comparison

Scenario	*PER (COP)*	*PES*	ψ_R	$\sum CO_2$	Pay-Back
Base Case	0,40	0,25	0,35	**1**	**1**
Scenario 1	0,15	0,30	0,45	0,55	0,8
Scenario 2	0,50	0,34	0,55	0,65	1,3

Overall, **Scenario 2** seems to be the best option among others. Yet there must be a reasonable amount of heating load in order to justify the ground-source heat pump. A direct mechanical drive between the ORC system and the GSHP may slightly improve the efficiency further but this option may reduce the flexibility of electric power driven option for the GSHP.

Discussion

Cooling by utilizing the thermal output of a CHP system has several alternatives.

These alternatives must be carefully selected on a case by case condition. However, the following rules may apply:

✓Check the dominance of cooling and heating loads in a year
✓Check the typical cooling and heating load profiles
✓**Make a careful optimization for pay-back period, energy savings, and environmental effect.**
✓**The use of low-exergy cooling systems and equipment must be sought.**

References

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